# Posteruptive Effects of Fluoridation on First Permanent Molars of Children in Grand Rapids, Michigan

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***This meticulously planned comparison of matched groups, balanced for caries susceptibility, reveals that fluoride added to drinking water will have a caries-inhibitory effect upon first permanent molars that have already erupted when fluoridation is begun.***

The discovery that there was less dental caries among children who had ingested fluoride-bearing water all their lives [1] led to the initiation in 1945 of several fluoridation studies.[2-4] These were designed to learn whether or not artificial fluoridation would also reduce the incidence of caries in children using fluoride from birth. It was apparent, from the reports of these [2, 4, 5] and other studies [6, 7] that caries was also inhibited in children who had ingested fluoridated water sometime during the period prior to the eruption of the permanent teeth. Not only did these preeruptive effects appear earlier than anticipated, but the data also suggested that there was a posteruptive inhibition of caries in first permanent molars.[4]

There is other evidence which shows that fluoride will inhibit caries when it is administered after the eruption of the permanent dentition. An early laboratory finding,[8] confirmed by other investigators,[9-11] demonstrated that rat molar teeth could be protected by fluoride given after the eruption of the teeth. In human beings posteruptive effects have been reported for natural fluoride-bearing waters [12-16] and for a topically applied fluoride solution.[17]

The present study is specifically concerned with determining whether or not artificial fluoridation will have any long-term caries inhibitory effect on human teeth already erupted when the water supply was fluoridated. This question has not been answered by any of the reports cited, as the studies dealing with posteruptive effects were of short duration, and those of long duration did not separate the posteruptive from the preeruptive effects.

The Grand Rapids fluoridation study [2, 19, 20] offered an opportunity to investigate the posteruptive effects of water fluoridation. In Grand Rapids there were children whose first permanent molars had erupted before fluoridation began and who had used fluoridated water since January, 1945, or about 11 years. In Muskegon, there were similar children who had used fluoridated water since July, 1951. The study situation was not ideal because the Muskegon children had been ingesting fluoridated water for nearly five years. However, those children who had first permanent molars in eruption in 1945 would have been at least 12 years of age in 1951. There is evidence [15] that posteruptive use of water containing as much as 3 ppm of natural fluoride does not affect the number of decayed, missing, or filled erupted first permanent molars of children 12 years of age or older but approximal surfaces, which continue to

decay after 12 years of age,[18] might be affected. In any event, comparison with Muskegon findings should result in a conservative estimate of the posteruptive effect in Grand Rapids.

## Selection of Children

From the 1944–1945 examination records of public school children who had then resided continuously in their respective cities since birth, the authors selected all of the first-grade children who had two or more first permanent molars in eruption at the time of the prefluoridation examinations. The directories of the two cities were consulted to identify the children whose families still resided in the same city. At the time of the examinations in April, 1956, 211 were enrolled in the five Grand Rapids public high schools and 141 in the Muskegon public high school. Of these, 196 were examined in Grand Rapids and 138 in Muskegon. For further retention in the study the Grand Rapids children were required to have used water fluoridated to a level of 1 ppm from January, 1945, to the date of examination in April, 1956. Muskegon children were required to have used no fluoride-bearing water prior to July, 1951, and no water containing fluoride in excess of 1 ppm since July, 1951. Vacation trips of 90 days or less were not considered. In all, 184 Grand Rapids and 133 Muskegon children met these requirements and were retained as the total study group.

## Procedure

The clinical examinations were performed with a mouth mirror, SSW No. 3 DE explorer and artificial illumination with a portable Castle T-V5A lamp. The first permanent molars were given a detailed examination and the size of restorations and cavities were schematically recorded by the examiner on diagrams of the first permanent molars.

Four sizes of first permanent molar lesions were recorded:

1. Small: A pit in which the explorer would catch, but could not be rocked; a restoration 1.5 mm or less in width; and smooth surface caries which could be so restored. An approximal cavity was recorded as small only if there was no approximating tooth.
2. Medium: A pit or fissure in which the explorer could be rocked, but which could not be diagnosed without use of the explorer; restorations resembling the ideal in size and shape; and smooth surface lesions which could be so restored, including approximal explorer catches.
3. Large: All cavities which could be diagnosed without use of the explorer, and restorations appreciably larger, in any dimension, than the ideal.
4. Pulp exposures: Cavities which, in the opinion of the examiner, involved the pulp. The explorer was not used on such cavities.

During the examinations models of typical small, medium, and large restorations were used for reference. If there was any doubt about the first molar being missing, the second molar was examined.

Posterior bite-wing x-rays were taken with a 5 ma 45 Kvp portable Oralix dental x-ray machine to which 1 mm of aluminum filtration had been added. At least four films were used for each person; more, including periapicals, were used for difficult cases. The angulation of the x-ray beam was varied as required by the alignment and shape of individual first molars. The Kodak DF-58 films were exposed for 1½ seconds and developed for three minutes at 68° F.

After the x-rays from the two cities were randomized so that the reader * did

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not know whether a given set of films was from Grand Rapids or Muskegon, the interpretations were made in two stages. First, the films were read for the sole purpose of identifying the first permanent molars. If there was any doubt about the presence or absence of a first permanent molar the x-rays were discussed with the other investigators and a decision reached by mutual agreement. These data were used to modify the clinical examinations. The films were then read for approximal caries of first permanent molars. Cavities and restorations were recorded as one of four depths: enamel only, shallow, moderate, or deep dentin. The classification was based upon the deepest penetration of caries or the deepest portion of the approximal restoration. For dentinal caries the distance from the dentinoenamel junction to the nearest point of the pulp was divided into thirds.

The value of this information about the size of the cavities was limited, unless it could be used to yield a single number that would express the caries experience of each individual. This number could then be used to compute group means and error terms. Borrowing the technics of other workers [21–24] the authors assigned scores to the clinical findings: a score of one was assigned to a small cavity or restoration, a score of two to a medium cavity or restoration, a score of three to a large cavity or restoration, and a score of four to a pulp exposure or a missing surface. The scores for each individual were totaled and divided by the number of surfaces at risk, i.e., the number of first molar surfaces present and caries-free in 1944–1945. The x-ray findings of enamel, shallow dentin, moderate dentin, and deep dentin were given scores of one, two, three, and four, respectively. Missing approximal surfaces were also given a score of four. The x-ray scores for each individual were totaled and divided by the number of approximal surfaces at risk. When the clinical and x-ray findings were combined, the larger of the two scores for a particular approximal surface was used. For convenience, the term "caries-score" will refer to the quotient:

$$\frac{\text{Sum of the scores for one individual}}{\text{Number of tooth surfaces at risk}}$$

"Mean caries-score" will, of course, signify a group score.

## Study Problems

The caries experience of all the six-year-old children in these cities was almost identical in 1944–1945.[2] The manner of drawing our samples, however, did not assure that our study groups would be representative of the whole six-year-old population examined in 1944–1945. The sample actually assembled from the first grade proved to be dissimilar with respect to caries experience in 1944–1945. Our Grand Rapids total study group had in 1944–1945 an average of 1.05 decayed, missing, or filled permanent teeth as compared with an average of 1.38 for our Muskegon group.

The original difference in caries susceptibility presented a problem in analysis as the long-term, posteruptive effect was not expected to be large enough to overwhelm this difference. Therefore, a matching process was used to select groups with the same initial caries experience. For each sex and each city the 1944–1945 examinations were separated into subgroups having the same total caries experience: the number of decayed, missing, or filled permanent teeth, plus the number of decayed, missing, or filled deciduous canines and molars. Examinations from these subgroups were matched for first permanent molars in eruption, number of first permanent molars with caries and, when possible, for location and severity of caries. Perfect matches were not possible in all instances, but care

**Table 1—Comparison of the Study Groups: Mean Age, Eruption and Caries-Status According to the 1944–1945 Clinical Examinations, Grand Rapids and Muskegon, Mich.**

| | Matched Study Group | | Unmatched Group | | Total Study Group | |
|---|---|---|---|---|---|---|
| | Grand Rapids | Muskegon | Grand Rapids | Muskegon | Grand Rapids | Muskegon |
| Number of children: | 116 | 116 | 68 | 17 | 184 | 133 |
| Males | 51 | 51 | 42 | 8 | 93 | 59 |
| Females | 65 | 65 | 26 | 9 | 91 | 74 |
| Mean age (years) | 6.46 | 6.65 | 6.62 | 6.02 | 6.52 | 6.57 |
| First permanent molars: | | | | | | |
| Number erupted | 410 | 413 | 240 | 58 | 650 | 471 |
| Mean number erupted | 3.53 | 3.56 | 3.53 | 3.40 | 3.53 | 3.54 |
| Number decayed, missing, or filled (DMF) | 136 | 137 | 56 | 43 | 192 | 180 |
| Adjusted mean number DMF * | 1.17 | 1.17 | 0.82 | 2.62 | 1.05 | 1.35 |
| Number of caries-free surfaces | 1,884 | 1,882 | 1,130 | 227 | 3,014 | 2,109 |
| Number of decayed or filled (DF) surfaces | 166 | 183 | 70 | 63 | 236 | 246 |
| Adjusted mean number DF surfaces * | 1.43 | 1.57 | 1.03 | 3.83 | 1.28 | 1.85 |
| Deciduous molars and canines: | | | | | | |
| Number decayed, missing, or filled | 770 | 771 | 272 | 158 | 1,042 | 929 |
| Mean No. decayed, missing, or filled | 6.64 | 6.65 | 4.00 | 9.29 | 5.66 | 6.98 |

* Adjusted to the number of teeth in eruption in Grand Rapids.

was taken to assure that the totals for the matched groups were similar.

The matching process, by excluding the older Grand Rapids children with low caries experience, resulted in two similar groups of 116 children each. The characteristics of the matched study groups are compared with the total study group and with the unmatched group in Table 1. In the matched group there were differences (not statistically significant) in mean age (about two and one-half months) and in the number of decayed or filled surfaces of first permanent molars. These differences might be related.

A second study problem was the identification of first permanent molars, which is not a new problem.[25, 26] In the total study group, when all first permanent molars (1,268) were used regardless of their 1944–1945 eruption status, there were 43 disagreements (3.4 per cent of all first molars) between the clinical and x-ray identification. There was reason to believe that the clinical examiner was correct for some of the disagreements, but the x-ray identification was accepted for the purpose of this study.

A third study problem was the comparability of the clinical and x-ray judgments of the size of restorations. This subject could not be directly examined since the two methods estimate different aspects of size: the clinical examination estimates size by surface area, the x-ray interpretation by depth. However, the ratio of depth (x-ray) to area (clinical) was 1.34 in Grand

Rapids and 1.30 in Muskegon. The small difference in these ratios is not considered important.

## Results and Interpretation

The data from the randomized x-rays indicate that fluoride does inhibit caries on the approximal surfaces of first molars erupted prior to fluoridation. Thus in the matched groups, there were more normal approximal surfaces present in Grand Rapids than in Muskegon, and the caries which was present was shallower in Grand Rapids. These findings are shown in Figure 1, which compares the approximal caries that occurred in the Grand Rapids matched group between 1944–1945 and 1956 with the approximal caries which occurred in Muskegon. These data present the clearest picture of the contrast between the two cities, but are difficult to subject to a statistical test because the surface, rather than the person, is the unit.

The data from the usual technic of adding the clinical and x-ray findings also suggest that fluoride confers a post-eruptive protection on first permanent molars. In the Grand Rapids matched group about 10 per cent fewer surfaces became decayed, missing, or filled between 1944–1945 and 1956 than in Muskegon. These data are presented in Table 2, which also includes the incremental caries experience of the unmatched children and of the total study group.

When the missing surface component is ignored, and the data from the matched group analyzed according to surface type (Table 3) it appears that there was a protective effect on all surfaces except the occlusal. Failure of the occlusal surface to derive benefit may be an artifact due to the placement of prophylactic restorations or to the restoration of this surface in the process of restoring approximal surfaces.

The mean caries-score for approximal surfaces of the matched groups also showed a difference between the Grand Rapids and Muskegon incidence of caries between 1944–1945 and 1956. This significant difference (0.05 level) was evidenced by clinical examinations alone, by x-ray alone, and by the combined technic (Table 4). It is also ap-

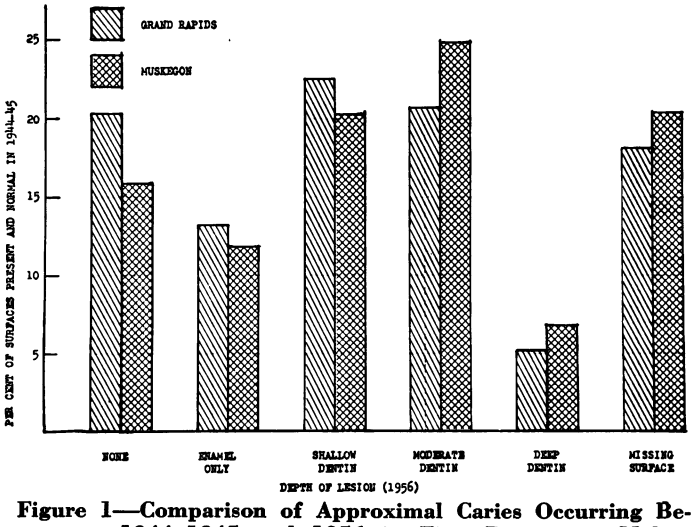


**Figure 1—Comparison of Approximal Caries Occurring Between 1944–1945 and 1956 in First Permanent Molars Erupted in 1944–1945, Grand Rapids and Muskegon Matched Groups, X-Ray Interpretations Only.**

**Table 2—Comparison of Incremental Caries Occurring Between 1944–1945 and 1956 in First Permanent Molars Erupted in 1944–1945, Grand Rapids and Muskegon Matched, Unmatched, and Total Groups, Clinical Examination Plus X-Ray Lesions of Dentin**

| | Matched Study Group | | Unmatched Group | | Total Study Group | |
|---|---|---|---|---|---|---|
| | Grand Rapids | Muskegon | Grand Rapids | Muskegon | Grand Rapids | Muskegon |
| Number of new decayed, missing, or filled surfaces (DMF) | 1,137 | 1,259 | 632 | 163 | 1,769 | 1,422 |
| New DMF surfaces per 100 surfaces at risk * | 60.4 | 66.9 | 55.9 | 71.8 | 58.7 | 67.4 |
| Number of missing teeth | 74 | 84 | 45 | 19 | 119 | 103 |
| Missing teeth per 100 teeth at risk * | 18.0 | 20.3 | 18.8 | 32.8 | 18.3 | 21.9 |

* The differences between the cities are not statistically significant.

parent that the magnitude of the difference is essentially the same whether one uses the combined technic (clinical plus x-ray) or x-rays alone. For comparison, Table 4 also includes the mean x-ray caries-scores for the total study group and for the unmatched children.

The occlusal and buccal+lingual surfaces in the matched study groups also had significantly lower caries-scores in Grand Rapids (Table 5), so that these data also support the belief that fluoride confers protection on teeth erupted prior to the initiation of fluoridation. It is interesting to note that the occlusal surfaces in Grand Rapids had lower caries-scores (Table 5) even though the number of surfaces affected was the same in the two cities (Table 3). This supports the previous suggestion that the protection is obscured by the restoration of noncarious surfaces. Another interesting finding is the similarity of the magnitude of the decreases in mean caries-scores for the approximal (0.28) and the buccal+lingual surfaces (0.27). As the caries susceptibilities of these two types of surfaces are very different, this finding is curious but its significance is not immediately apparent.

## Significance

The findings that there were fewer and smaller cavities in Grand Rapids

**Table 3—Comparison of Surfaces Becoming Decayed or Filled Between 1944–1945 and 1956 in First Permanent Molars Erupted in 1944–1945, Grand Rapids and Muskegon Matched Groups, Clinical Examinations Plus X-Ray Lesions of Dentin**

| | Occlusal Surface | | Buccal+Lingual Surfaces | | Mesial+Distal Surfaces | |
|---|---|---|---|---|---|---|
| | Grand Rapids | Muskegon | Grand Rapids | Muskegon | Grand Rapids | Muskegon |
| Number of new decayed or filled surfaces | 226 | 226 | 194 | 239 | 402 | 437 |
| Mean number of new decayed or filled surfaces * | 1.95 | 1.95 | 1.67 | 2.06 | 3.46 | 3.77 |

* The differences between the cities are not statistically significant.

**Table 4—Mean Caries-Scores for Approximal Surfaces Becoming Decayed or Filled Between 1944–1945 and 1956; First Permanent Molars Erupted in 1944–1945, Grand Rapids and Muskegon**

| | X-Rays Only | | | Clinical : Clinical+X-Ray | |
|---|---|---|---|---|---|
| | Total Group | Unmatched | Matched Group | Matched Study Group | |
| Muskegon | 1.99 | 1.97 | 1.99 | 1.22 | 2.02 |
| Grand Rapids | 1.67 | 1.57 | 1.73 | 0.83 | 1.74 |
| Difference | 0.32 | 0.40 | 0.26 | 0.39 | 0.28 |
| Standard error of difference | .. | .. | 0.12 | 0.11 | 0.12 |

indicate that fluoride will have a caries-inhibitory effect on first permanent molars that have already erupted when fluoridation is initiated and support the more general hypothesis concerning the posteruptive effects of fluoride.[16] However, the data probably underestimate the posteruptive caries-inhibitory effect on the whole dentition for two reasons. First, the Muskegon children did use fluoridated water for the last five years of the study period and it is probable that there was some inhibition of the caries process, particularly on the approximal surfaces of the first permanent molars in Muskegon. Second, other investigators [27, 28] have shown that other tooth types are proportionately better protected than the molars. It is, then, reasonable to assume that incisors, canines, and premolars would show greater proportional changes in caries experience than were found in this study.

## Summary and Conclusions

Clinical and bite-wing x-ray examinations were performed in April, 1956, on the Grand Rapids and Muskegon public school children who in 1944–1945 were continuous residents and had two or more first permanent molars in eruption. Fluoridated water had been ingested by 184 of the Grand Rapids children since January, 1945, and by 133 of the Muskegon children since July, 1951. These children had satisfactory fluoride histories. The size of the cavities and restorations in first permanent molars were recorded by the clinical examiner at the time of examination and by the x-ray examiner after the x-rays from the two cities were randomized. A caries scoring system was used to put the data into a form that could be statistically tested and the comparability of the clinical and x-ray findings was investigated. The final

**Table 5—Comparison of Mean Caries-Scores for Surfaces Becoming Decayed or Filled Between 1944–1945 and 1956, First Permanent Molars Erupted in 1944–1945, Matched Groups of Grand Rapids and Muskegon Children, Clinical+X-Ray**

| | Occlusal | Buccal+Lingual | Mesial+Distal | All Surfaces |
|---|---|---|---|---|
| Muskegon | 2.08 ± 0.07 * | 0.88 ± 0.08 | 2.02 ± 0.09 | 1.56 ± 0.07 |
| Grand Rapids | 1.85 ± 0.07 | 0.61 ± 0.07 | 1.74 ± 0.08 | 1.29 ± 0.06 |
| Difference | 0.23 ± 0.10 | 0.27 ± 0.11 | 0.28 ± 0.12 | 0.27 ± 0.09 |

* Standard error.

analysis was based on new caries in teeth erupted prior to fluoridation in matched groups of 116 children each. These matched groups, which were balanced for caries susceptibility in 1944–1945, were selected from the children with satisfactory fluoride histories.

The data indicated that the Grand Rapids children consistently had fewer and smaller cavities than the Muskegon children. For all surfaces the mean caries-score was 17 per cent lower in Grand Rapids, for approximal surfaces 14 per cent lower, for buccal+lingual surfaces 31 per cent, and for occlusal surfaces 11 per cent lower than in Muskegon. The findings support the hypothesis that artificial fluoridation will inhibit caries in teeth that have erupted prior to fluoridation.

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